Fabrication of High Thermal Conductivity NARloy-Z-Diamond Composite Combustion Chamber Liner for Advanced Rocket Engines

Biliyar N. Bhat
Materials and Processes Laboratory
NASA- Marshall Space Flight Center, Huntsville, Alabama

January 6, 2016

57th AIAA Structures, Structural Dynamics and Materials Conference
San Diego, CA

Materials and Processes Development Team

- NASA-MSFC
  - Biliyar Bhat – Principal Investigator
  - Sandra Greene – Co-Investigator – chamber design and testing
  - Enrique Jackson – thermal conductivity
  - James Coston, Ellen Rabenberg – microscopy
  - Will Tilson/Jacobs – tensile testing
  - Supported by NASA-MSFC Technology Investment Project
- NASA-GRC
  - Dr. David Ellis - consultant
- Penn State – Applied Research Laboratory
  - Dr. Jogender Singh – FAST processing
- Momentive Performance Materials
  - Aaron Rape – thermal conductivity
- Global Technology Enterprises
  - Dr. Sion Pickard – coated diamonds

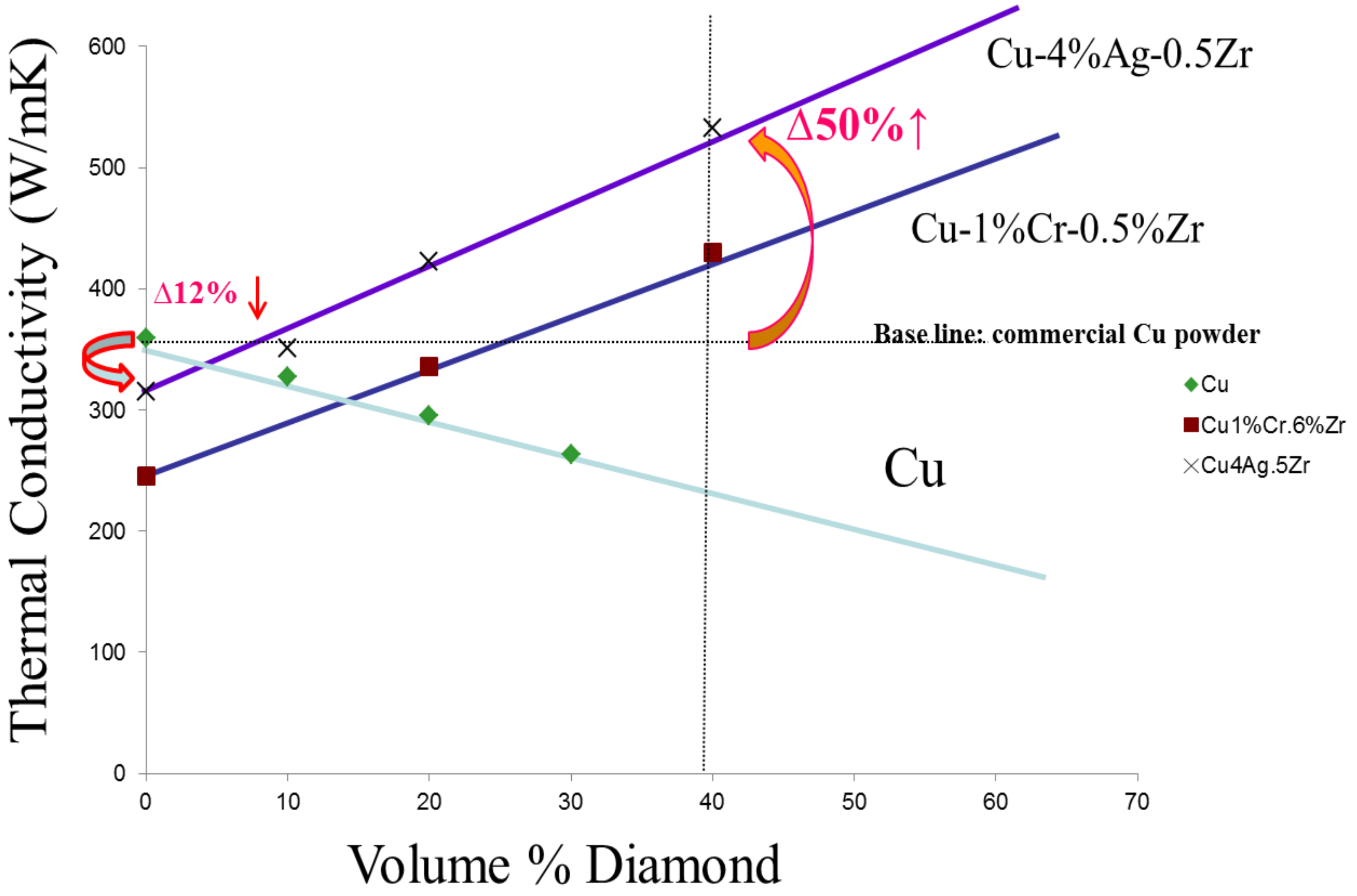
Overview

- Introduction
- Improving thermal conductivity of copper alloys
- Project goals
- Chamber liner fabrication process
- Field Assisted Sintering Technology (FAST)
- Diffusion bonding
- Fabrication challenges
- Results
- Follow on work

Introduction

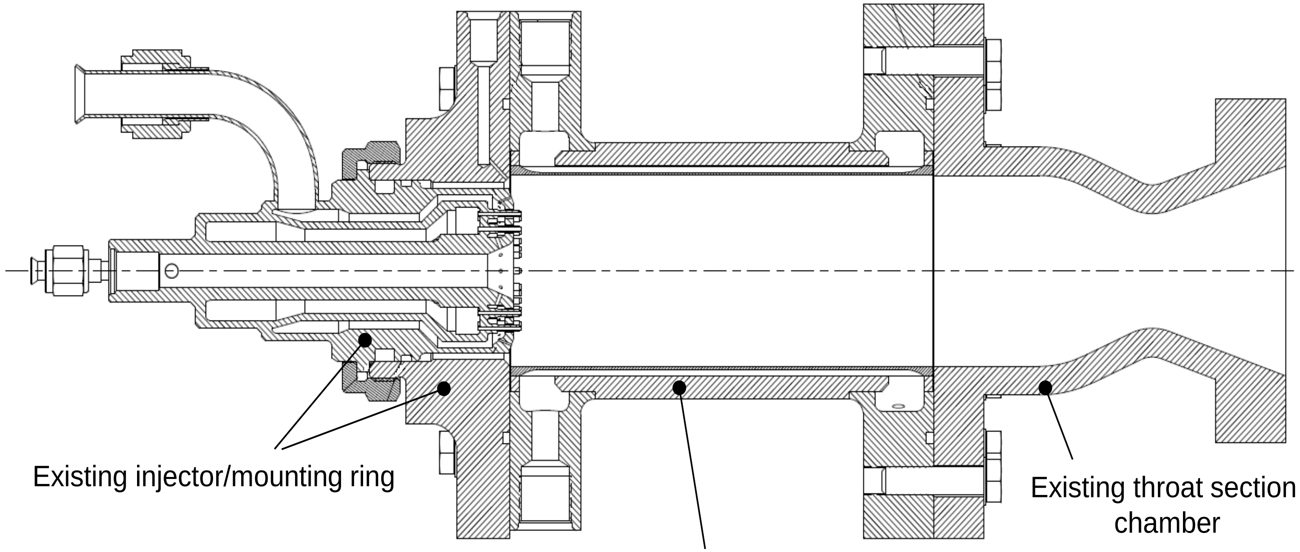
- NARloy-Z alloy (Cu-3Ag-0.5Zr) is state of the art material for making combustion chamber liner for liquid rocket engines. Thermal conductivity (TC)– 320 W/mK
  - Currently used in RS-25, RS-68
- Improved TC will help to improve the performance of rocket engines
  - Improved turbopump power, thrust to weight ratio, specific impulse
- Prior work on NARloy-Z-Diamond composites showed promise
  - 50% improvement in thermal conductivity relative to copper
- Technology development goals:
  - Fabricate a subscale combustion chamber liner (TRL 4)
  - Fabricate test chamber assembly
  - Hot fire test to demonstrate performance improvements (TRL 5)

Thermal conductivity of Cu-Ag-Zr-D composites



Combustion chamber liner, chamber assembly

B A



- Chamber liner (A) – 2.75”OD, 2.5” ID, 8” long
- Chamber assembly (B)

Hot fire test assembly schematic

Chamber liner fabrication steps

NARloy-Z powder

Diamond powder

→ NARloy-Z-D mixture

Turbula mixer

→ Pour into TZM mold

→ FAST Sinter at elevated temperature and pressure

→

NARloy-Z-D ring

↓

Multiple rings stacked in TZM mold

← FAST Diffusion bond at elevated temperature and pressure

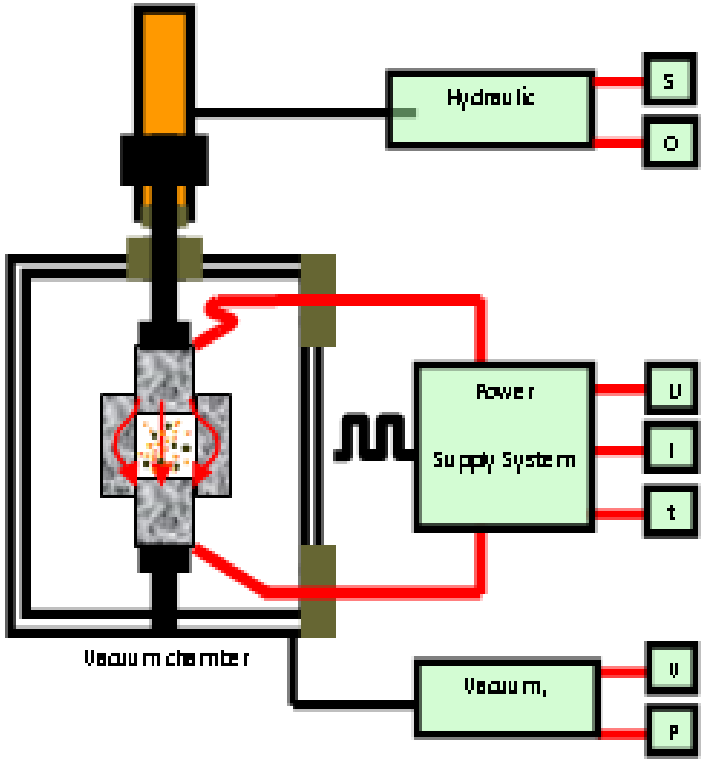
←

Liner removed from mold

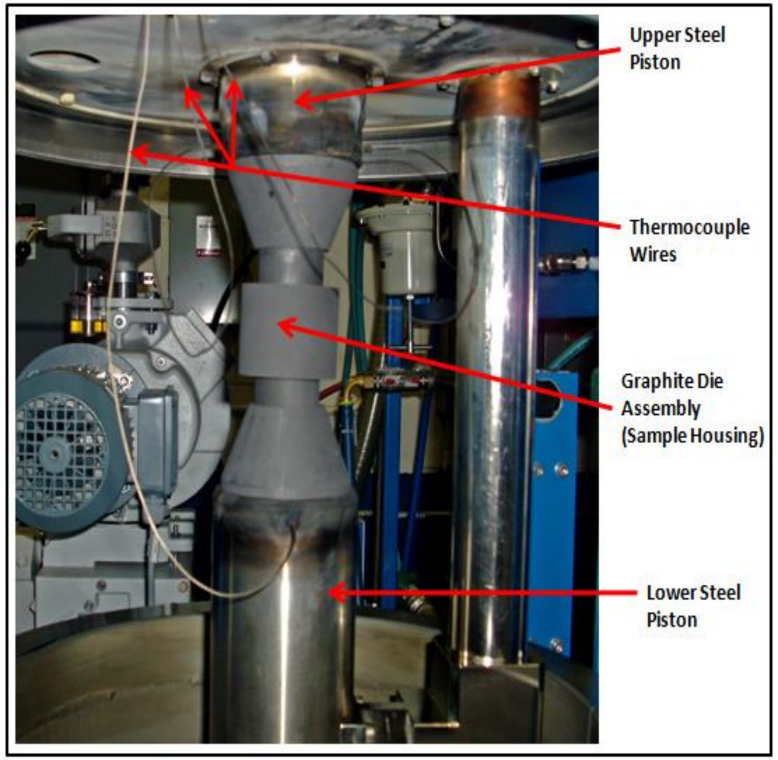
←

Finished liner

Field Assisted Sintering Technology (FAST)



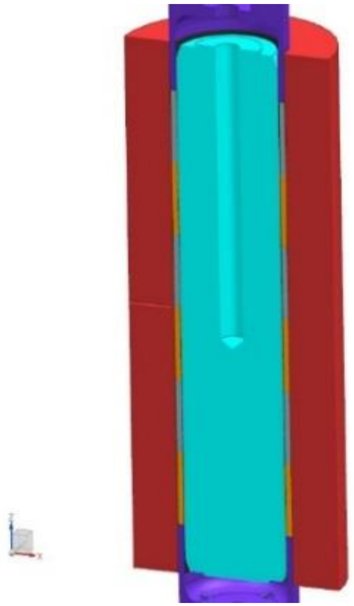
FAST - schematic



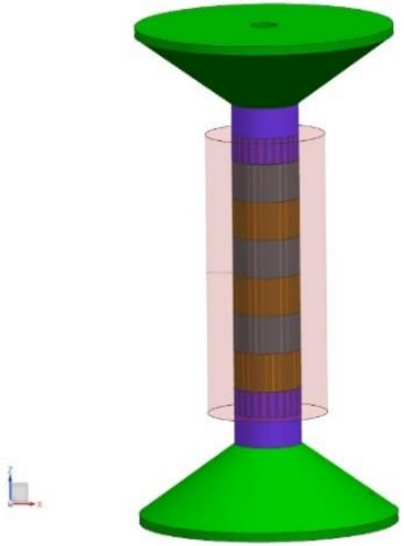
FAST system at Penn State - ARL

Sintering at high temperature in FAST apparatus

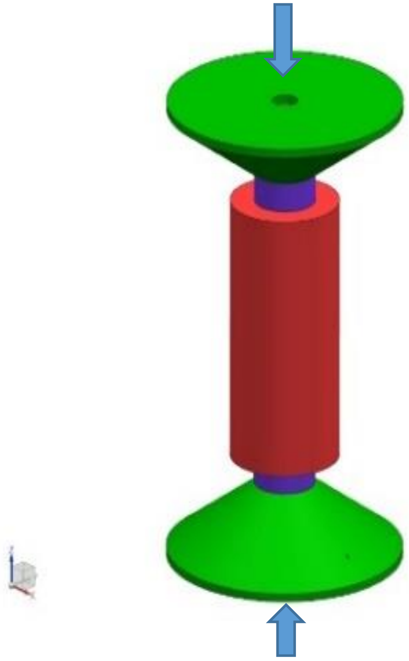
Diffusion bonding (schematic)



Eight rings stacked inside TZM mold for joining



Translucent model with multi-colors showing the rings



Diffusion bonding by FAST

Fabrication challenges

- Machining of NARloy-Z-D composite
  - Too hard to machine by conventional means
  - EDM and water jet cutting successful
- Near net shape forming
  - Switching from graphite to TZM molds for better strength at elevated temperatures
- Segregation of diamonds in microstructure
  - Diamonds segregate easily – hard to homogenize
  - Metal coatings help to improve mixing – Ti, Cu
  - Cu coating worked better
- Copper coated diamonds – supplied by GTE
  - Coating of MoC for better contact conductance
  - Overcoat of Cu for better mixing and sintering
- Diffusion bonding of NARloy-D rings
  - Interlayer of NARloy-Z for better bonding
- Microscopy and NDE
  - Material is too hard to make metallographic samples
  - Freshly fractured surfaces the best way to examine microstructure in SEM
  - CT scanning to assess segregation and ensure quality

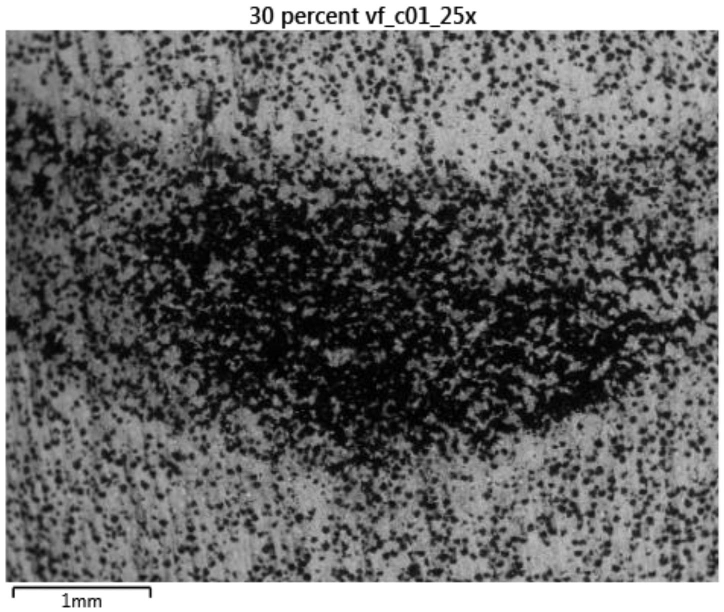
Tensile properties (preliminary)

Sample type	Composition	Test temperature, Environment	YS, ksi	UTS, ksi	Elongation, %
NARloy-Z	Base line	75^{o}F, air	18	45	33
NARloy-Z-30D	30 vol% diamond	75^{o}F, air	19	19	<1
NARloy-Z-40D	40 vol% diamond	75^{o}F, air	18-20	18-24	<1
NARloy-Z-40D	40 vol% diamonds	935^{o}F, GN2	11	11	<1
NARloy-Z-30(Ti-D)	30 vol% Ti-coated diamond	75^{o}F, air	12	12-13	<1
NARloy-Z-30 (Cu-MoC-D)	28 vol% diamonds, Cu-MoC coated	70^{o}F, air	18	23	2-3
NARloy-Z-30 (Cu-MoC-D)	28 vol% diamonds, Cu-MoC coated	1000^{o}F, 250 psi He	5-6	5-7	2-3
Diffusion bonded NARloy-Z-40D	40 vol.% Diamond; NARloy-Z at bond line	70^{o}F, air	10	11	<1

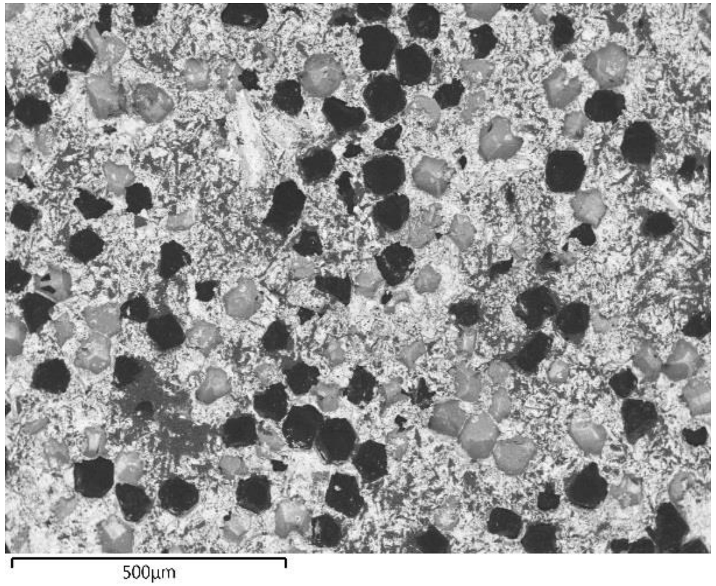
Thermal conductivity (preliminary)

Sample chemistry (vol%)	Thermal conductivity (W/m-K)	Temperature, ºK	Comments
NARloy-Z	320	300	Base line (Ref. 2)
NARloy-Z-30%D	337	380	Diamond segregation observed (Ref. 3)
NARloy-Z-40%D	344	380	Diamond segregation observed (Ref. 3)
NARloy-30%TiD	176	300	Ti lowers TC
NARloy-Z-28%CuD	462	300	TC acceptable

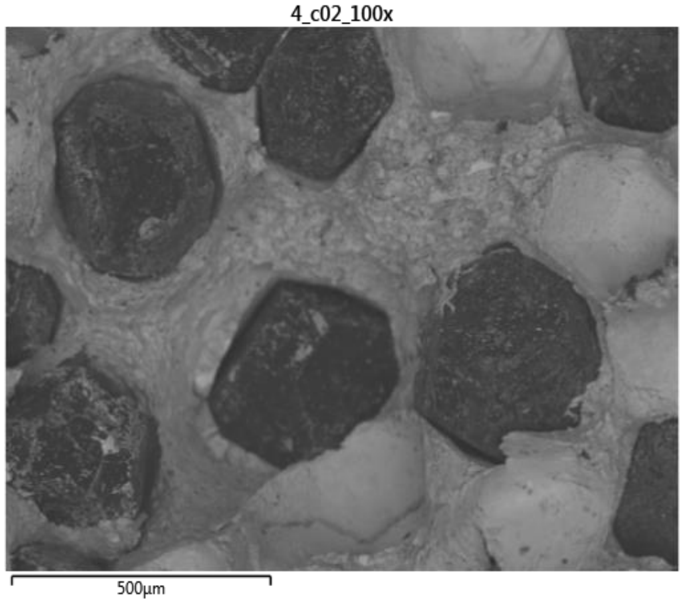
Microstructure



SEM Micrograph showing diamond segregation (dark area) in NARloy-Z-30%D Composite



SEM fractograph of NARloy-Z-Ti coated diamond composite



SEM fractograph of NARloy-Z-Cu-MoC coated diamond composite

Chamber liner

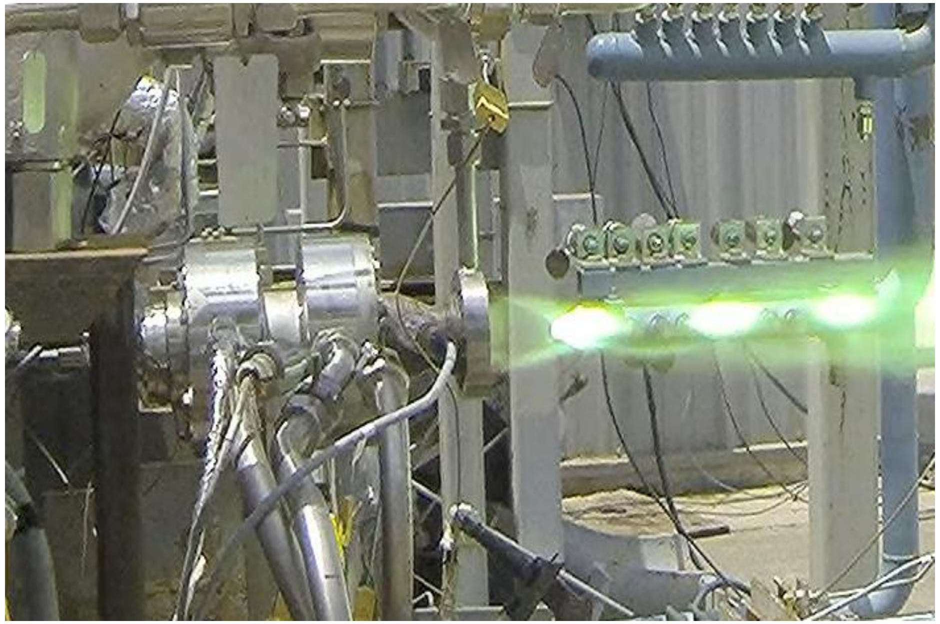
Chamber liner ring (2.5” ID., 2.75” OD, 1.0” long) made from NARloy-Z- CuD composite

NARloy-Z chamber liner fabricated by FAST - after taking out of the mold

NARloy-Z chamber liner – after cleaning

Follow on work

- Diffusion bond NARloy-Z-CuD composite rings in FAST apparatus
- Machine cooling channels by water jet grinding
- Electroplate with nickel to close out the channels
- Fabricate coolant manifolds and integrate with hot fire test assembly
- Hot fire test in MSFC test stand 115
- Analyze data and assess performance



Hot fire testing at MSFC TS 115

Summary and Conclusions

- Successfully formulated a high thermal conductivity NARloy-Z-CuD composite material that can be processed into shapes.
- Developed processing technique for combustion chamber liner rings by use of Field Assisted Sintering Technology (FAST)
- Developed fabrication technique for chamber liner by diffusion bonding
- This is a break through technology in metal matrix composites, which will help to make our future propulsion systems lighter and higher performance using a high thermal conductivity material for combustion chamber liner.
- Materials and processing technologies can be developed further to optimize properties for specific applications, e.g., heat exchangers and other thermal management systems.